



## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

<b>(51) International Patent Classification <sup>6</sup> :</b>  <b>H01M</b>	<b>A2</b>	<b>(11) International Publication Number:</b> <b>WO 99/67829</b>  <b>(43) International Publication Date:</b> 29 December 1999 (29.12.99)
<b>(21) International Application Number:</b> PCT/US99/12255  <b>(22) International Filing Date:</b> 1 June 1999 (01.06.99)  <b>(30) Priority Data:</b> 09/089,856      3 June 1998 (03.06.98)      US  <b>(71) Applicant:</b> INTERNATIONAL FUEL CELLS CORPORATION [US/US]; 195 Governor's Highway, South Windsor, CT 06074 (US).  <b>(72) Inventors:</b> FULLER, Thomas, F.; 300 Chestnut Hill Road, Glastonbury, CT 06033 (US). MARGIOTT, Paul, R.; 32 Sele Drive, South Windsor, CT 06074 (US). VAN DINE, Leslie, L.; 117 Plymouth Lane, Manchester, CT 06040 (US).  <b>(74) Agent:</b> KELLY, Robert, H.; Intellectual Property Counsel, Hamilton Standard, One Hamilton Road, Windsor Locks, CT 06096-1010 (US).		<b>(81) Designated States:</b> AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, GH, GM, HU, ID, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, UZ, VN, YU, ZW, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).  <b>Published</b> <i>Without international search report and to be republished upon receipt of that report.</i>
<b>(54) Title:</b> DIRECT MASS AND HEAT TRANSFER FUEL CELL POWER PLANT  		
<b>(57) Abstract</b>  <p>A direct mass and heat transfer fuel cell power plant invention includes at least one fuel cell and a direct mass and heat transfer device. The fuel cell includes an electrolyte, an anode electrode and a cathode electrode supported respectively by a porous anode support layer and a porous cathode support layer in intimate contact with opposed surfaces of the electrolyte. A reducing fluid stream and an oxidant inlet stream flow at about ambient pressure through the support layers. The direct mass and heat transfer device passes the oxidant inlet stream upstream of the fuel cell in mass transfer relationship with a cathode exhaust stream leaving the cell so that mass such as water vapor picked up by the cathode exhaust stream passes directly through a transfer medium of the mass and heat transfer device into the oxidant stream entering the cell, thereby humidifying and adding heat to the oxidant stream entering the cell. The direct mass transfer device includes a separator housing for supporting the transfer medium in mass transfer relationship with the cathode exhaust stream and oxidant inlet stream so that the streams contact the transfer medium and the separator housing prevents bulk mixing of the streams. The transfer medium may comprise any of a variety of materials that sorb a fluid substance consisting of polar molecules within a stream including fluid substances consisting of polar and non-polar molecules. An exemplary transfer medium includes a liquid water portion of polyfluorosulfonic ionomer membrane.</p>		

**FOR THE PURPOSES OF INFORMATION ONLY**

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	ES	Spain	LS	Lesotho	SI	Slovenia
AM	Armenia	FI	Finland	LT	Lithuania	SK	Slovakia
AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Latvia	SZ	Swaziland
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TG	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav Republic of Macedonia	TM	Turkmenistan
BF	Burkina Faso	GR	Greece	ML	Mali	TR	Turkey
BG	Bulgaria	HU	Hungary	MN	Mongolia	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MR	Mauritania	UA	Ukraine
BR	Brazil	IL	Israel	MW	Malawi	UG	Uganda
BY	Belarus	IS	Iceland	MX	Mexico	US	United States of America
CA	Canada	IT	Italy	NE	Niger	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NL	Netherlands	VN	Viet Nam
CG	Congo	KE	Kenya	NO	Norway	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NZ	New Zealand	ZW	Zimbabwe
CI	Côte d'Ivoire	KP	Democratic People's Republic of Korea	PL	Poland		
CM	Cameroon	KR	Republic of Korea	PT	Portugal		
CN	China	KZ	Kazakhstan	RO	Romania		
CU	Cuba	LC	Saint Lucia	RU	Russian Federation		
CZ	Czech Republic	LI	Liechtenstein	SD	Sudan		
DE	Germany	LK	Sri Lanka	SE	Sweden		
DK	Denmark	LR	Liberia	SG	Singapore		
EE	Estonia						

## Description

## DIRECT MASS AND HEAT TRANSFER FUEL CELL POWER PLANT

## Technical Field

The present invention relates to fuel cell power  
5 plants that operate at about ambient pressures and are  
suited for usage in transport vehicles, as portable power  
plants, or as stationary power plants, and the invention  
especially relates to a fuel cell power plant that  
transfers mass and heat, such as water vapor, exiting the  
10 plant back into the plant to enhance water balance and  
energy efficiency of the plant.

## Background of the Invention

Fuel cell power plants are well-known and are commonly  
used to produce electrical energy from reducing and  
15 oxidizing fluids to power electrical apparatus such as  
apparatus on-board space vehicles. In such power plants, a  
plurality of planar fuel cells are typically arranged in a  
stack surrounded by an electrically insulating frame that  
defines manifolds for directing flow of reducing,  
20 oxidizing, coolant and product fluids. Each individual  
cell generally includes an anode electrode and a cathode  
electrode separated by an electrolyte. A reactant or  
reducing fluid such as hydrogen is supplied to the anode  
electrode, and an oxidant such as oxygen or air is supplied  
25 to the cathode electrode. In a cell utilizing a proton  
exchange membrane as the electrolyte, the hydrogen  
electrochemically reacts at a surface of an anode catalyst  
to produce hydrogen ions and electrons. The electrons are  
conducted to an external load circuit and then returned to  
30 the cathode electrode, while the hydrogen ions transfer  
through the electrolyte to the cathode electrode, where  
they react with the oxidant and electrons to produce water

and release thermal energy.

The anode and cathode electrodes of such fuel cells are separated by different types of electrolytes depending on operating requirements and limitations of the working environment of the fuel cell. One such electrolyte is a proton exchange membrane ("PEM") electrolyte, which consists of a solid polymer well-known in the art. Other common electrolytes used in fuel cells include phosphoric acid or potassium hydroxide held within a porous, non-conductive matrix between the anode and cathode electrodes. It has been found that PEM cells have substantial advantages over cells with liquid acid or alkaline electrolytes in satisfying specific operating parameters because the membrane of the PEM provides a barrier between the reducing fluid and oxidant that is more tolerant to pressure differentials than a liquid electrolyte held by capillary forces within a porous matrix. Additionally, the PEM electrolyte is fixed, and cannot be leached from the cell, and the membrane has a relatively stable capacity for water retention. As is well-known however, PEM cells have significant limitations especially related to liquid water transport to, through and away from the PEM, and related to simultaneous transport of gaseous reducing and oxidant fluids to and from the electrodes adjacent opposed surfaces of the PEM. The prior art includes many efforts to minimize the effect of those limitations.

In operation of a fuel cell employing a PEM, the membrane is saturated with water, and the anode electrode adjacent the membrane must remain wet. As hydrogen ions produced at the anode electrode transfer through the electrolyte, they drag water molecules in the form of hydronium ions with them from the anode to the cathode. Water also transfers back to the anode from the cathode by osmosis. Product water formed at the cathode electrode is removed by evaporation or entrainment into a circulating gaseous stream of oxidant, or by capillary action into and

through a porous fluid transport layer adjacent the cathode.. Porous water transport plates supply liquid water from a supply of coolant water to the anode electrode and remove water from the cathode electrode returning it back  
5 to the coolant water supply, and the plates thereby also serve to remove heat from the electrolyte and electrodes.

In operation of PEM fuel cells, it is critical that a proper water balance be maintained between a rate at which water is produced at the cathode electrode and rates at  
10 which water is removed from the cathode and at which liquid water is supplied to the anode electrode. An operational limit on performance of a fuel cell is defined by an ability of the cell to maintain the water balance as electrical current drawn from the cell into the external  
15 load circuit varies and as an operating environment of the cell varies. For PEM fuel cells, if insufficient water is returned to the anode electrode, adjacent portions of the PEM electrolyte dry out thereby decreasing the rate at which hydrogen ions may be transferred through the PEM and  
20 also resulting in cross-over of the reducing fluid leading to local over heating. Similarly, if insufficient water is removed from the cathode, the cathode electrode may become flooded effectively limiting oxidant supply to the cathode and hence decreasing current flow. Additionally, if too  
25 much water is removed from the cathode by the gaseous stream of oxidant, the cathode may dry out limiting ability of hydrogen ions to pass through the PEM, thus decreasing cell performance.

As fuel cells have been integrated into power plants  
30 developed to power transportation vehicles such as automobiles, trucks, buses, etc., maintaining an efficient water balance within the power plant has become a greater challenge because of a variety of factors. For example, with a stationary fuel cell power plant, water lost from  
35 the plant may be replaced by water supplied to the plant from off-plant sources. With a transportation vehicle,

however, to minimize weight and space requirements of a fuel cell power plant the plant must be self-sufficient in water to be viable. Self-sufficiency in water means that enough water must be retained within the plant to offset losses from a stream of reactant fluid to efficiently operate the plant. For example, any water exiting the plant through a cathode exhaust stream of gaseous oxidant or through an anode exhaust stream of gaseous reducing fluid must be balanced by water produced electrochemically at the cathode and retained within the plant.

One approach to enhancing water balance for fuel cell power plants in transportation vehicles is to pressurize the cell and related components to increase reactant concentrations in high pressure gaseous streams and thereby reduce water loss through plant exhaust streams. Such pressurized fuel cell power plants, however, require additional cost, weight and control apparatus in providing appropriate pressure housings and controls, and pressurized plants require additional energy derived from the plant to operate pressurizing pumps, valves, fans, etc., and are not practical for portable power plants.

Another common approach to enhancing water balance is use of condensing heat exchangers downstream of power plant exhaust streams wherein the exhaust streams are cooled to a temperature at or below their dew points to precipitate liquid out of the exhaust streams so that the liquid may be returned to the power plant. An example of a PEM fuel cell power plant using a condensing heat exchanger is shown in U.S. Patent No. 5,573,866 that issued on November 12, 1996 to Van Dine et al., and is assigned to the assignee of the present invention, and which patent is hereby incorporated herein by reference. Many other fuel cell power plants that use one or more condensing heat exchangers are well-known in the art, and they typically use ambient air streams as a cooling fluid passing through the exchanger to cool the plant exhaust streams. In Van Dine et al., the

heat exchanger is used to cool an exhaust stream exiting a cathode chamber housing the cathode electrode. Prior to entering the cathode housing, the same stream provides air as the oxidant for the cathode electrode, and upon leaving  
5 the chamber the stream includes evaporated product water and some portion of methanol, the reducing fluid, that has passed through the PEM. The condensing heat exchanger passes the cathode exhaust stream in heat exchange relationship with a stream of cooling ambient air, and then  
10 directs condensed methanol and water indirectly through a piping system back to an anode side of the cell.

While condensing heat exchangers have enhanced water balance and energy efficiency of ambient and pressurized fuel cell power plants, the heat exchangers encounter  
15 decreasing water recovery efficiency as ambient temperatures increase. Where the power plant is to power a transportation vehicle such as an automobile, the plant will be exposed to an extremely wide range of ambient temperatures. For example where an ambient air coolant  
20 stream passes through a heat exchanger, performance of the exchanger will vary as a direct function of the temperature of the ambient air because decreasing amounts of liquid precipitate out of power plant exhaust streams as the ambient air temperature increases.

25 An additional complication of known fuel cell power plants designed for use in transportation vehicles is also related to fluctuations in ambient air conditions. Fuel cells of such plants typically utilize ambient air as the oxidant directed to the cathode electrode. Hot and dry  
30 ambient air increases a risk that the cathode electrode will dry out. Consequently, many efforts have been undertaken to prevent drying out of the cathode electrode and adjacent electrolyte especially in PEM fuel cells, including: directing liquid condensate from heat exchangers  
35 to humidify gaseous reactant and oxidant streams entering the cell; adding porous support layers and water transport

plates in fluid communication with the electrodes for movement of coolant water through adjacent cells; and, generating a pressure differential on the anode side of the cell wherein gaseous reducing fluids are maintained at a slightly higher pressure than coolant water and anode supply water passing through the porous support layers adjacent reducing gas distribution channels so that the pressure differential assists water transport through the porous support layers and cell. Such efforts at maintaining efficient water balance involve additional cost, weight and volume, and often require complicated control apparatus.

Further problems of maintaining water balance in known fuel cell power plants are associated with components necessary to process hydrocarbon fuels, such as methane, natural gas, gasoline, or diesel fuel, etc., into an appropriate reducing fluid that provides a hydrogen rich fluid to the anode electrode. Such fuel processing components of a fuel cell power plant typically include an auxiliary burner that generates steam; a steam duct into which the hydrocarbon fuel is injected; and an autothermal reformer that receives the steam, fuel mixture and a small amount of air and transforms the mixture into a hydrogen-enriched reducing fluid appropriate for delivery to the anode electrode of the fuel cell. These fuel processing components also include water and energy requirements that are part of an overall water balance and energy requirement of the fuel cell power plant. Water made into steam in a steam generator of the auxiliary burner must be replaced by water recovered from the plant such as by condensing heat exchangers in the cathode exhaust stream and associated piping. Additionally, process oxidant streams that also support the auxiliary burner and autothermal reformer must be maintained within a stable humidity range to prevent variations in performance of those components. When the oxidant process streams for the fuel processing components



are supplied by ambient air, humidifying the streams to stabilize performance of those fuel processing components further complicates maintenance of a self-sufficient water balance of such a fuel cell power plant.

5           Accordingly, known pressurized plants and plants that employ ambient air as the cathode oxidant or that employ ambient air for condensing heat exchangers and/or fuel processing components are incapable of maximizing an efficient water balance and minimizing operating energy  
10 requirements because of their above described characteristics. It is therefore highly desirable to produce a fuel cell power plant that achieves an efficient water balance for the entire plant and minimizes plant operating energy requirements.

15   Disclosure of the Invention

          The invention is a direct mass and heat transfer fuel cell power plant. The power plant includes two major components being at least one fuel cell and a direct mass and heat transfer device. The fuel cell includes an  
20 electrolyte that has opposed first and second major surfaces, an anode electrode supported by a porous anode support layer in intimate contact with the first major surface and a cathode electrode supported by a porous cathode support layer in intimate contact with the second  
25 major surface, a hydrogen rich reducing fluid stream flowing at about ambient pressure through the anode support layer in contact with the anode electrode, and an oxidant stream such as air flowing at about ambient pressure through the cathode support layer in contact with the  
30 cathode electrode to provide oxidant to the cathode electrode and to remove by evaporation and entrainment into a cathode exhaust stream product water formed at the cathode along with water carried through the electrolyte from the anode electrode or any humidification water in the  
35 oxidant stream. The direct mass and heat transfer device

passes the stream of oxidant upstream of the fuel cell in mass transfer relationship with the cathode exhaust stream downstream of the cell so that mass such as water picked up by the cathode exhaust stream passes directly through a transfer medium of the mass and heat transfer device into the oxidant stream entering the cell, thereby humidifying and adding heat to the oxidant stream entering the cell. The direct mass transfer device includes a separator housing for supporting the transfer medium in mass transfer relationship with the cathode exhaust stream and oxidant inlet stream so that the streams contact the transfer medium and the separator housing prevents bulk mixing of the streams. The transfer medium may comprise any of a variety of materials for sorbing a fluid substance consisting of polar molecules such as water molecules from a fluid stream containing fluid substances consisting of polar and non-polar molecules. An exemplary transfer medium includes a liquid water portion of a water saturated polyflourosulfonic ionomer membrane.

In an alternative embodiment, the power plant of the present invention also includes components for processing hydrocarbon fuels into hydrogen rich reducing fluids appropriate for providing fuel to the anode. The fuel processing components include an auxiliary burner that provides heat to a steam generator and an autothermal reformer that receives the steam mixed with the hydrocarbon fuel and a small amount of air and converts it to a hydrogen rich stream appropriate for supplying hydrogen to the anode electrode as is well-known in the art. In such an embodiment, the direct mass and heat transfer device also passes process streams entering the auxiliary burner and autothermal reformer in mass transfer relationship with the cathode exhaust stream to transfer mass and heat such as water vapor to the streams entering the auxiliary burner and autothermal reformer. In a further preferred embodiment, the electrolyte of the fuel cell is a proton

exchange membrane ("PEM").

In use of the direct mass and heat transfer fuel cell power plant, because the mass transfers directly from the cathode exhaust stream into the oxidant streams entering the power plant, a rate of uptake of the mass and therefore heat by the oxidant streams is not solely a function of ambient air temperature or humidity, but instead is a function of partial pressure differences between mass in the oxidant streams entering the power plant and the mass in the cathode exhaust exiting the plant. The present invention therefore permits greater water recovery than is possible with a plant using an ambient air cooled condensing heat exchanger which has a water recovery rate that is largely a function of ambient temperatures. With the present invention, if the ambient air temperature increases, a required heat transfer from the cathode exhaust to the entering oxidant streams for optimal plant efficiency decreases, however a mass transfer capacity of the direct transfer device remains constant. Additionally, complex, heavy and costly condensing heat exchange and/or cell pressurization apparatus are not needed, thereby increasing water balance and energy efficiency of the plant while decreasing weight, volume and cost.

Accordingly, it is a general object of the present invention to provide a direct mass and heat transfer fuel cell power plant that overcomes deficiencies of prior art fuel cell power plants.

It is a more specific object to provide a direct mass and heat transfer fuel cell power plant that is self-sufficient in water over a broad range of operating conditions.

It is yet another object to provide a direct mass and heat transfer fuel cell power plant that returns to the plant water and heat exiting the plant without pressurizing fluid streams within the plant and without utilizing a condensing heat exchanger.

It is still a further object to provide a direct mass and heat transfer fuel cell power plant that directly transfers mass and heat exiting the power plant back into oxidant streams entering fuel cells of the power plant to  
5 humidify and heat those streams.

It is yet another specific object to provide a direct mass and heat transfer fuel cell power plant that recovers water exiting the plant in a cathode exhaust stream to provide water as a reactant to components for processing  
10 hydrocarbon fuels utilized by the plant.

These and other objects and advantages of this invention will become more readily apparent when the following description is read in conjunction with the accompanying drawings.

15

#### Brief Description of the Drawings

Figure 1 is a schematic representation of a direct mass and heat transfer fuel cell power plant constructed in  
20 accordance with the present invention.

Figure 2 is schematic representation of the Figure 1 direct mass and heat transfer fuel cell power plant utilizing components for processing hydrocarbon fuels into fuels appropriate for a fuel cell.

#### 25 Description of the Preferred Embodiments

Referring to the drawings in detail, a direct mass and heat transfer fuel cell power plant of the present invention is shown and generally designated by the reference numeral 10. As best seen in Figure 1, the power  
30 plant 10 includes at least one fuel cell 12 and a direct mass and heat transfer device 14. The fuel cell 12 includes an electrolyte 16 such as a proton exchange membrane ("PEM") or an acid or base electrolyte having a first major surface 18 and an opposed second major surface  
35 20; an anode electrode 22 supported by a porous anode

support layer 24 in intimate contact with the first major surface 18 of the electrolyte 16; and, a cathode electrode 26 supported by a porous cathode support layer 28 in intimate contact with the second major surface 20 of the electrolyte 16. The anode and cathode porous support layers 24, 28 may be formed of porous or channeled graphite, carbon or metal sheets. The fuel cell 12 may be combined with other virtually identical fuel cells in a well-known manner to form a stack. As is common in the art, the fuel cell 12 may be enclosed within a structure 30 that defines manifolds for directing streams of reducing fluids and oxidants into and out of the cell, and the structure 30 also includes electrical conduction means for directing an electrical current generated by the fuel cell out of the cell 12 to an electricity using device 32, such as through a standard external load circuit 34.

An oxidant stream such as air is directed from an oxidant source 36 into the fuel cell 12 through a primary oxidant passage 38 that passes a stream of oxidant into the porous cathode support layer 28 so that the oxidant passes in contact with the cathode electrode 26 to provide oxidant to the electrode 26 for facilitating an electrochemical reaction at the cathode electrode and for sweeping into the oxidant stream by evaporation and/or entrainment water formed at the cathode electrode 26 as well as water carried through the electrolyte 16 from the anode electrode 22 or any humidification water in the oxidant stream. The oxidant stream then passes out of the cathode support layer 28 as a cathode exhaust stream within a cathode exhaust passage 40. A reducing fluid stream is directed from a reducing fluid supply source 42 through a reducing fluid inlet 44 into the porous anode support layer 24 so that the reducing fluid such as hydrogen comes into contact with the anode electrode 22. In a well-known manner, the reducing fluid electrochemically reacts at the anode electrode to produce protons and electrons, wherein the electrons flow

through the external load circuit 34 to power the electrical device 32 such as electric motors powering a transport vehicle, while the protons travel through the electrolyte 16 to the cathode electrode 26. The electrons  
5 then continue through the circuit 34 to the cathode electrode where they react with the oxidant to form water and heat.

The direct mass and heat transfer device 14 is secured in fluid communication with both the primary oxidant  
10 passage 38 and the cathode exhaust passage 40. The direct mass and heat transfer device 14 includes a transfer medium means 46 for sorbing a fluid substance consisting of polar molecules within a first fluid stream containing fluid substances consisting of polar and non-polar molecules,  
15 such as a stream including water vapor and/or entrained liquid moisture (being a fluid substance consisting of polar molecules) and air (being a fluid substance consisting of non-polar molecules), and for desorbing the sorbed fluid into a second stream having a lower proportion  
20 of the fluid substance consisting of polar molecules than the first stream. Exemplary transfer medium means include a liquid water portion of an ion exchange resin or an ionomeric membrane such as a water saturated polyflourosulfonic ionomer membrane sold under the brand  
25 name "NAFION" by the E.I. DuPont company of Willmington, Delaware, U.S.A., or a liquid water portion of tubes made of the aforesaid "NAFION" membrane and sold under the brand name "ME-SERIES MOISTURE EXCHANGERS" by the Perma Pure, Inc. company of Toms River, New Jersey, U.S.A. An  
30 additional transfer medium includes a desiccant material capable of sorbing moisture from a gaseous stream and capable of desorbing the moisture into a gaseous stream  
such as finely powdered solid, crystalline alkali metal or alkaline earth metal compounds including active carbons,  
35 silica gel, activated aluminas and zeolites as described in more detail at Column 5, line 9 to Column 6, line 17 in

U.S. Patent No. 5,542,968 issued on August 6, 1996 to Belding et al., which patent is hereby incorporated herein by reference.

The direct mass transfer device 14 also includes a separator housing means 48 for supporting the transfer medium means 46 in mass transfer relationship with the cathode exhaust stream and the oxidant inlet stream so that both streams contact the mass transfer medium means and the separator housing means prevents bulk mixing of the cathode exhaust and oxidant inlet streams. Exemplary separator housing means may include an enclosure (shown schematically in FIGS. 1 and 2 at reference number 48) that supports the transfer medium means 46 between an inlet chamber 50 and an exhaust chamber 52. The oxidant inlet stream passes from the oxidant source 36 through an oxidant feed line 54 into and through the inlet chamber 50 into the primary oxidant passage 38, while the cathode exhaust stream passes from the cathode exhaust passage 40 into and through the exhaust chamber 52 to leave the plant 10 through a plant exhaust 56 in fluid communication with the exhaust chamber 52. Additional separator housing means 48 may include more complicated enclosures structured to enhance exposure of the oxidant inlet and cathode exhaust streams to the mass transfer medium means while preventing bulk mixing of the streams such as are common in known fluid to fluid heat exchanger art. An additional and cooperative aspect of the separator housing means 48 includes membrane portions supporting liquid water portions in the aforesaid "NAFION" membrane materials and tube portions supporting liquid water in the aforesaid "NAFION"-based tubes that are sold under the brand name "ME-SERIES MOISTURE EXCHANGERS" by Perma Pure, Inc. In such a separator housing means 48, "NAFION"-based mass transfer medium means will selectively transfer fluid substances consisting of polar molecules such as water vapor or entrained liquid moisture from a side of the membrane having a greatest concentration of the

fluid substances consisting of polar molecules to a side having a lesser concentration in a manner well-known in the art.

A further exemplary separator housing means includes  
5 an enthalpy wheel that supports the aforesaid desiccant mass transfer medium means in a rotational disposition between a moisture laden exhaust stream and a dry inlet stream, as described in more detail at Column 4, line 35 to Column 5, line 4 and generally throughout the aforesaid  
10 U.S. Patent No. 5,542,968. The wheel includes a plurality of open ended passages running generally parallel to an axis of rotation of the wheel, wherein the passages are typically formed by winding a flat sheet of corrugated paper board including the mass transfer medium desiccant  
15 around a central hub of the wheel until a multi-layered media is built up that extends to an outer housing of a cassette supporting the wheel. Such enthalpy wheels are well-known in building air-conditioning arts, as further described in U.S. Patent No. 5,660,048 that issued on  
20 August 26, 1997 to Bedding et al. and is incorporated herein by reference. As a separator housing means, the enthalpy wheel would be supported to rotate about an axis parallel to flow through the inlet and exhaust chambers 50, 52 so that the cathode exhaust stream passes through about  
25 one-half of the wheel while simultaneously the oxidant inlet stream passes through the other half of the wheel. The transfer medium means desiccant on a first portion of the wheel within the exhaust chamber 52 would thereby sorb a fluid substance consisting of polar molecules such as  
30 water vapor or entrained liquid moisture from the cathode exhaust stream and, when the wheel rotates to position that first portion of the wheel into the inlet chamber 50, if the concentration of the fluid substance consisting of polar molecules within the inlet oxidant stream is less  
35 than the concentration of the fluid substance consisting of fluid molecules within the cathode exhaust stream, the



sorbed polar molecule fluid substance held by the desiccant would be desorbed into the oxidant inlet stream to humidify and heat the oxidant stream.

As shown in FIG. 1, the direct mass transfer fuel cell power plant 10 may also include a blower 58 positioned on the oxidant feed line 54 to variably accelerate flow of gaseous oxidant into the plant 10. Optionally, the blower 58 may be positioned along the primary oxidant passage 38 for the same purposes. It is stressed, however, that the blower is of a capacity to only slightly increase operating pressures of the oxidant to a range of from atmospheric pressure to about 1.0 P.S.I.A. above atmospheric pressure, or from about 14.7 P.S.I.A. to about 15.7 P.S.I.A.

As shown in FIG. 2, the direct mass transfer fuel cell power plant 10 may also include fuel processing component means for processing hydrocarbon fuels into reducing fluids appropriate for providing fuel to an anode electrode of a fuel cell. Exemplary hydrocarbon fuels for powering such a plant 10 include gasoline, diesel fuel, butane, propane, natural gas, methanol, ethanol, etc.

In FIG. 2, components of the plant 10 that are identical to the FIG. 1 schematic representation of the plant 10 are given the same reference numerals. As shown in FIG. 2, the fuel processing component means may include: an auxiliary burner 60 (labelled "AUX. BURNER" in FIG. 2 for convenience) that burns a fuel including any excess reducing fluid such as hydrogen fed to the burner 60 through line 62 from the anode support layer 24 and cell structure 30; a steam generator 64 (labelled "STEAM" in FIG. 2) that receives heat directly from the burner in heat conduit 66 to generate steam from a supply of water; a reformer 68 that may be an autothermal reformer (labelled "A.T.R." in FIG. 2) that receives steam from the steam generator 64 mixed with the hydrocarbon fuel through steam line 70; a hydrocarbon fuel supply source 72 (labelled "FUEL" in FIG. 2) that supplies the fuel to the steam line

through fuel line 74; and a reformed fuel discharge line 75 that directs the reformed fuel from the autothermal reformer 68 into the reducing fluid inlet 44. The fuel processing component means may also include components that  
5 are well-known in conventional steam reforming, autothermal reforming of various chemical compounds, and partial oxidation reforming, all of which include a reformer 68.

As seen in FIG. 2, where the plant 10 includes such fuel processing components, the primary oxidant passage 38  
10 that supplies the oxidant stream to the cathode support layer may be split to include a secondary oxidant passage 76 that directs a portion of the oxidant inlet stream into the fuel processing component means such as into the steam line 70 to become process oxidant for the autothermal  
15 reformer so that a portion of the mass and heat such as water vapor recovered from the cathode exhaust into the oxidant stream by the mass transfer device 14 is directed into the steam and fuel mixture entering the autothermal reformer. In that manner, the overall heat and steam  
20 requirements of the auxiliary burner 60 and steam generator 64 are lessened.

To further support the fuel processing components, the primary oxidant passage 38 may be further split to include a tertiary oxidant passage 78 that directs a portion of the  
25 oxidant inlet stream into the auxiliary burner 60 to become process oxidant for the burner 60 thereby directing some of the mass and heat such as water vapor transferred from the cathode exhaust stream by the mass transfer device 14 into the burner 60 to effectively decrease energy requirements  
30 of the burner 60 and direct water recovered from the plant cathode exhaust stream back into the plant 10 to effectively supplement water within the steam generator 64 and enhance water self-sufficiency of the plant 10. The fuel processing components are of relatively conventional  
35 design that are generally well-known in the chemical processing arts wherein there is a need to generate

hydrogen enriched fluid from common hydrocarbon sources. For example, autothermal reformers in such processes typically burn a portion of the fuel received in the fuel-steam mixture to reach temperatures approximating 1,700  
5 degrees fahrenheit (hereafter "°F"). It is also well-known in such reforming processes to pass autothermal reformer product gasses through a water shift reactor 79 and then a selective oxidizer 81 and then into the reducing fluid inlet 44 so that a reducing fluid stream in the inlet 44  
10 includes hydrogen and carbon dioxide, with very small amounts of carbon monoxide.

In an additional embodiment of the direct mass transfer fuel cell power plant 10 a coolant water loop means may be included for recycling water recovered from  
15 the fuel cell 12 to the fuel processing components to further enhance plant water self-sufficiency. The coolant water loop means includes a fine pore water plate 80 adjacent the cathode support layer 28 that sorbs water formed at the cathode electrode and/or water passing  
20 through the electrolyte 16; and a coolant water line 82 that directs water in the porous water plate 80 into the fuel processing component means such as into the steam generator 64 to further supplement the water supply of the steam generator. As can be seen in FIG. 2, some of that  
25 water then passes through the steam line 70 into the autothermal reformer 68, and from there through the reformed fuel discharge line 75 and reducing fluid inlet 44 back into the anode support layer 24, and may then pass through the electrolyte 16 and back into the porous water  
30 plate 80 to complete a "loop" of the coolant water loop means. The coolant water loop means may also include a fine pore water plate adjacent the anode support layer 24, and in such a sequence between each cell in a stack, as shown in more detail in U.S. Patent No. 5,505,944 that  
35 issued on April 26, 1996 to Meyer et al., which patent is owned by the assignee of the present invention and which

patent is hereby incorporated herein by reference.

A design estimate of performance of the direct mass transfer fuel cell power plant 10 as shown in FIG. 1 produces data demonstrating substantial advantages over  
5 comparable fuel cell power plants that do not employ a mass transfer device 14. The design estimate utilizes a "NAFION"-based membrane having a water transfer rating of about 160 pounds of water per hour as the transfer medium within a separator housing that passes an oxidant inlet  
10 stream in mass transfer relationship with a cathode exhaust stream. For purposes of the design estimate, the fuel cell has a power capacity of 50 kilowatts. The oxidant inlet stream leaves the blower 58 at a pressure of 15.4 PSIA, a flow of 190 CFM, a temperature of 77°F, and a dew point of  
15 less than 32°F. After exiting the mass transfer device 14, the oxidant stream within the primary oxidant passage 38 is saturated at 147°F. The cathode exhaust stream within the cathode exhaust passage 40 leaves the fuel cell 12 and enters the mass transfer device 14 at 190°F with a dew point  
20 of 152°F; and the cathode stream then leaves the mass transfer device 14 in the plant exhaust at a temperature of 152°F and a dew point of 95°F, and a flow rate of 216 CFM.

As is apparent by contrasting the characteristics of the oxidant stream between the primary oxidant passage 38  
25 and the blower 58 the direct mass transfer device 14 substantially increases moisture and heat content of the oxidant stream entering the cathode support layer 28 with virtually no energy expenditure of the plant 10, and no ancillary piping or control apparatus to direct liquid  
30 condensate back into the cathode inlet stream. The components that make up the direct mass and heat transfer fuel cell power plant 10 are of made of conventional materials well-known in the art, except for the materials that are described in detail herein, such as the transfer  
35 medium means.

While the present invention has been described and

illustrated with respect to a particular construction and method of use of the direct mass and heat transfer fuel cell power plant, it is to be understood that the present invention is not to be limited to the described and  
5 illustrated embodiments. For example, while reference has been made to water requirements of a fuel cell using a PEM as an electrolyte, it is to be understood that any electrolyte common to known fuel cells may be employed in the plant. Accordingly, reference should be made primarily  
10 to the following claims rather than the foregoing description to determine the scope of the invention.

15

## CLAIMS

1. A direct mass and heat transfer fuel cell power plant for generating electrical energy from a reducing fluid and an oxidant fluid, the plant comprising:
- a. at least one fuel cell, including;
    - 5 i. an electrolyte having a first major surface and an opposed second major surface; and
    - ii. an anode electrode supported by a porous anode support layer in intimate contact with the first major surface of the electrolyte and a cathode electrode supported by a porous cathode support layer in intimate contact with the second major surface of the electrolyte, wherein the porous anode support layer passes a stream of the reducing fluid in contact with the anode electrode and the porous cathode support layer passes a stream of the oxidant in contact with the cathode electrode;
  - 10 b. a primary oxidant passage that passes an oxidant inlet stream at about ambient pressure from a supply of oxidant into the porous cathode support layer;
  - c. a cathode exhaust passage that passes a cathode exhaust stream out of the porous cathode support layer; and,
  - 15 d. a direct mass and heat transfer device secured in fluid communication with the primary oxidant passage and with the cathode exhaust passage, including;
    - 20 i. a transfer medium means for sorbing a fluid substance consisting of polar molecules within the cathode exhaust stream and for desorbing the fluid substance consisting of
    - 25
    - 30

35 polar molecules into the oxidant inlet  
stream; and  
ii. a separator housing means for  
supporting the transfer medium means in mass  
transfer relationship with the cathode  
40 exhaust stream and oxidant inlet stream so  
that both streams contact the mass transfer  
medium means, and for preventing bulk mixing  
of the cathode exhaust and oxidant inlet  
streams.

2. The direct mass and heat transfer fuel cell power plant of Claim 1, wherein the transfer medium means comprises a liquid water portion of an ionomeric membrane.

3. The direct mass and heat transfer fuel cell power plant of Claim 2, wherein the separator housing means comprises membrane portions supporting the liquid water of the ionomeric membrane.

4. The direct mass and heat transfer fuel cell power plant of Claim 1, wherein the transfer medium means comprises a liquid water portion of ionomeric membrane tubes.

5. The direct mass and heat transfer fuel cell power plant of Claim 4, wherein the separator housing means comprises tube portions supporting the liquid water in the ionomeric membrane tubes.

6. The direct mass and heat transfer fuel cell power plant of Claim 1, wherein the transfer medium means comprises a desiccant material capable of sorbing moisture from a gaseous stream and capable of desorbing moisture

5 into a gaseous stream.

7. The direct mass and heat transfer fuel cell power plant of Claim 6, wherein the separator housing means comprises an enthalpy wheel supporting the desiccant material in a plurality of passages running generally  
5 parallel to an axis of rotation of the enthalpy wheel and the enthalpy wheel is rotationally supported within inlet and exhaust chambers of the separator housing so that the wheel rotates about an axis parallel to flow of the oxidant inlet stream through the inlet chamber and the cathode  
10 exhaust stream through the exhaust chamber to directly transfer sorbed moisture from the exhaust stream to the oxidant inlet stream.

8. The direct mass and heat transfer fuel cell power plant of Claim 1, wherein the electrolyte is a proton exchange membrane.

9. A direct mass and heat transfer fuel cell power plant for generating electrical energy from a reducing fluid and an oxidant fluid, the plant comprising:

- a. at least one fuel cell, including;
  - 5 i. an electrolyte having a first major surface and an opposed second major surface; and
  - ii. an anode electrode supported by a porous anode support layer in intimate contact with the first major surface of the electrolyte and a cathode electrode supported by a  
10 porous cathode support layer in intimate contact with the second major surface of the electrolyte, wherein the porous anode support layer passes a stream of the  
15 reducing fluid in contact with the anode



- electrode and the porous cathode support layer passes a stream of the oxidant in contact with the cathode electrode;
- 20        b. fuel processing component means for processing hydrocarbon fuels into hydrogen rich reducing fluids appropriate for providing fuel to the anode electrode;
- 25        c. a primary oxidant passage that passes an oxidant inlet stream from a supply of oxidant into the porous cathode support layer;
- d. a secondary oxidant passage that passes a portion of the oxidant inlet stream into the fuel processing component means as a process oxidant for the fuel processing component means;
- 30        f. a cathode exhaust passage that passes a cathode exhaust stream out of the porous cathode support layer; and,
- e. a direct mass and heat transfer device secured in fluid communication with the primary and secondary oxidant passages and with the cathode exhaust passage, including;
- 35        i. a transfer medium means for sorbing a fluid substance consisting of polar molecules within the cathode exhaust stream and for
- 40        desorbing the fluid substance consisting of polar molecules into the oxidant inlet stream; and
- ii. a separator housing means for supporting the transfer medium means in mass transfer relationship with the cathode exhaust stream and oxidant inlet stream so
- 45        that both streams contact the mass transfer medium means, and for preventing bulk mixing of the cathode exhaust and oxidant inlet

50 streams.

10. The direct mass and heat transfer fuel cell power plant of Claim 9, wherein the fuel processing component means includes an auxiliary burner that provides heat to a steam generator, a reformer that receives steam from the steam generator mixed with the hydrocarbon fuel through a steam line between the steam generator and the reformer, a supply source of the hydrocarbon fuel that feeds the hydrocarbon fuel into the steam line, and a reformed fuel discharge line that directs the reformed fuel into the anode support layer, and wherein the secondary oxidant passage directs a portion of the oxidant inlet stream into the steam line.

11. The direct mass and heat transfer fuel cell power plant of Claim 10, wherein the plant includes a tertiary oxidant passage in fluid communication with the direct mass and heat transfer device that passes a portion of the oxidant inlet stream into the auxiliary burner.

12. The direct mass and heat transfer fuel cell power plant of Claim 11, wherein the transfer medium means comprises a liquid water portion of an ionomeric membrane and the separator housing means comprises membrane portions supporting the liquid water of the ionomeric membrane.

13. The direct mass and heat transfer fuel cell power plant of Claim 11, wherein the transfer medium means comprises a liquid water portion of ionomeric membrane tubes and the separator housing means comprises tube portions supporting the liquid water in the ionomeric membrane tubes.

14. The direct mass and heat transfer fuel cell power plant of Claim 11, wherein the transfer medium means comprises a desiccant material capable of sorbing moisture from a gaseous stream and capable of desorbing moisture  
5 into a gaseous stream.

15. The direct mass and heat transfer fuel cell power plant of Claim 14, wherein the separator housing means comprises an enthalpy wheel supporting the desiccant material in a plurality of passages running generally  
5 parallel to an axis of rotation of the enthalpy wheel and the enthalpy wheel is rotationally supported within inlet and exhaust chambers of the separator housing so that the wheel rotates about an axis parallel to flow of the oxygen inlet stream through the inlet chamber and the cathode  
10 exhaust stream through the exhaust chamber to directly transfer sorbed moisture from the exhaust stream to the oxidant inlet stream.

16. The direct mass and heat transfer fuel cell power plant of Claim 9, wherein the electrolyte is a proton exchange membrane.

17. A method of operating a fuel cell power plant for direct transfer of mass and heat, the method comprising the steps of:

- a. providing at least one fuel cell, including;
  - 5 i. an electrolyte having a first major surface and an opposed second major surface; and
  - ii. an anode electrode supported by a porous anode support layer in intimate contact with  
the first major surface of the electrolyte  
10 and a cathode electrode supported by a porous cathode support layer in intimate

- 15 contact with the second major surface of the electrolyte, wherein the porous anode support layer passes a stream of the reducing fluid in contact with the anode electrode and the porous cathode support layer passes a stream of the oxidant in contact with the cathode electrode;
- 20 b. passing an oxidant inlet stream through a primary oxidant passage at about ambient pressure from a supply of oxidant into the porous cathode support layer;
- 25 c. passing a cathode exhaust stream through a cathode exhaust passage out of the porous cathode support layer; and,
- 30 d. directing the oxidant inlet stream and cathode exhaust stream in mass transfer relationship within a direct mass and heat transfer device by passing the oxidant inlet stream and cathode exhaust stream in contact with a transfer medium for sorbing a fluid substance consisting of polar molecules within the cathode exhaust stream and for desorbing the fluid substance consisting of polar molecules into the oxidant inlet stream by
- 35 further supporting the mass transfer medium within a separator housing so that both streams contact the mass transfer medium and both streams are prevented from bulk mixing together.

18. The method of operating the fuel cell power plant of Claim 17, further comprising the step of passing a portion of the oxidant inlet stream through a secondary oxidant passage into fuel processing components of the plant as a

---

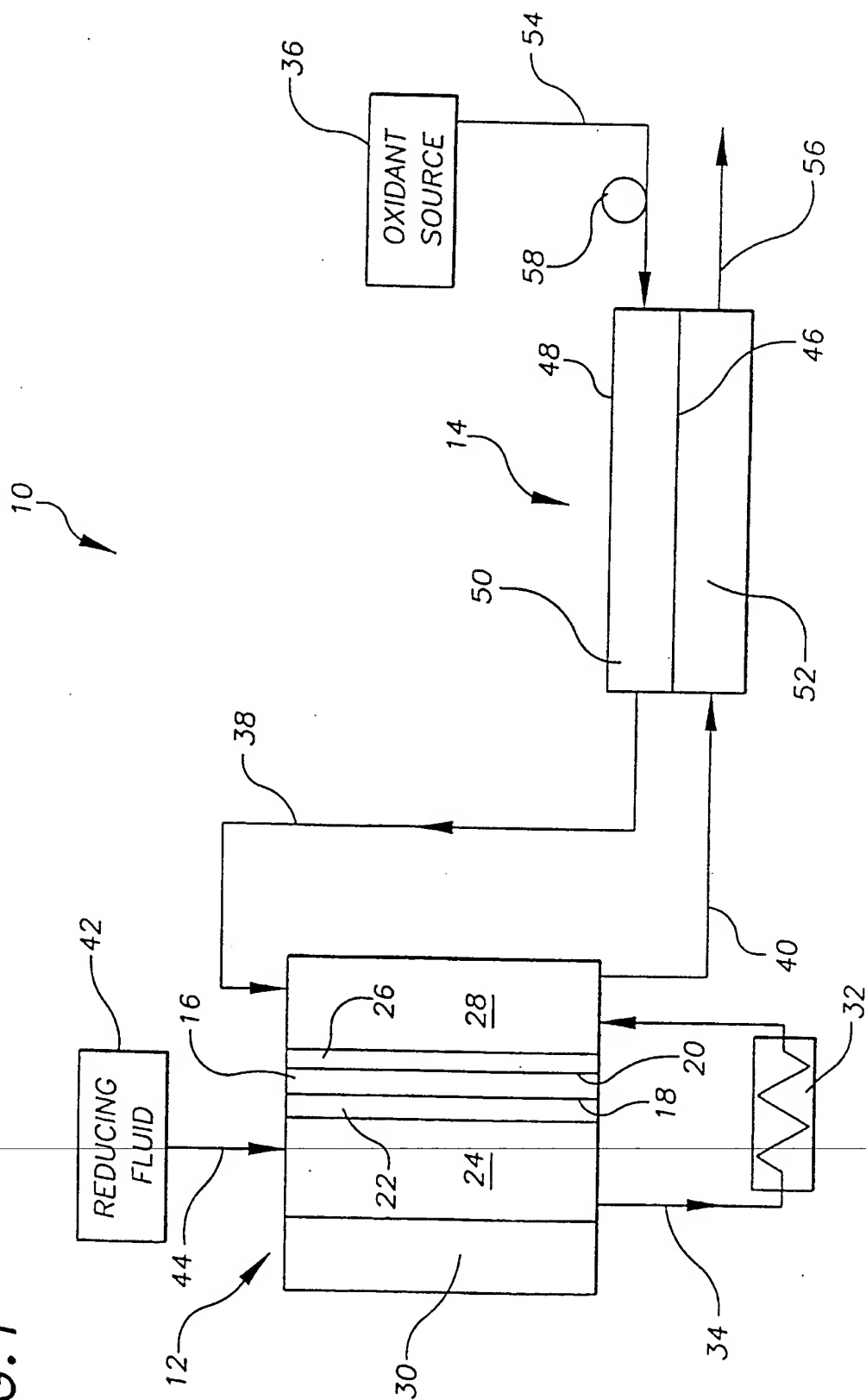
5 process oxidant for the fuel processing components.

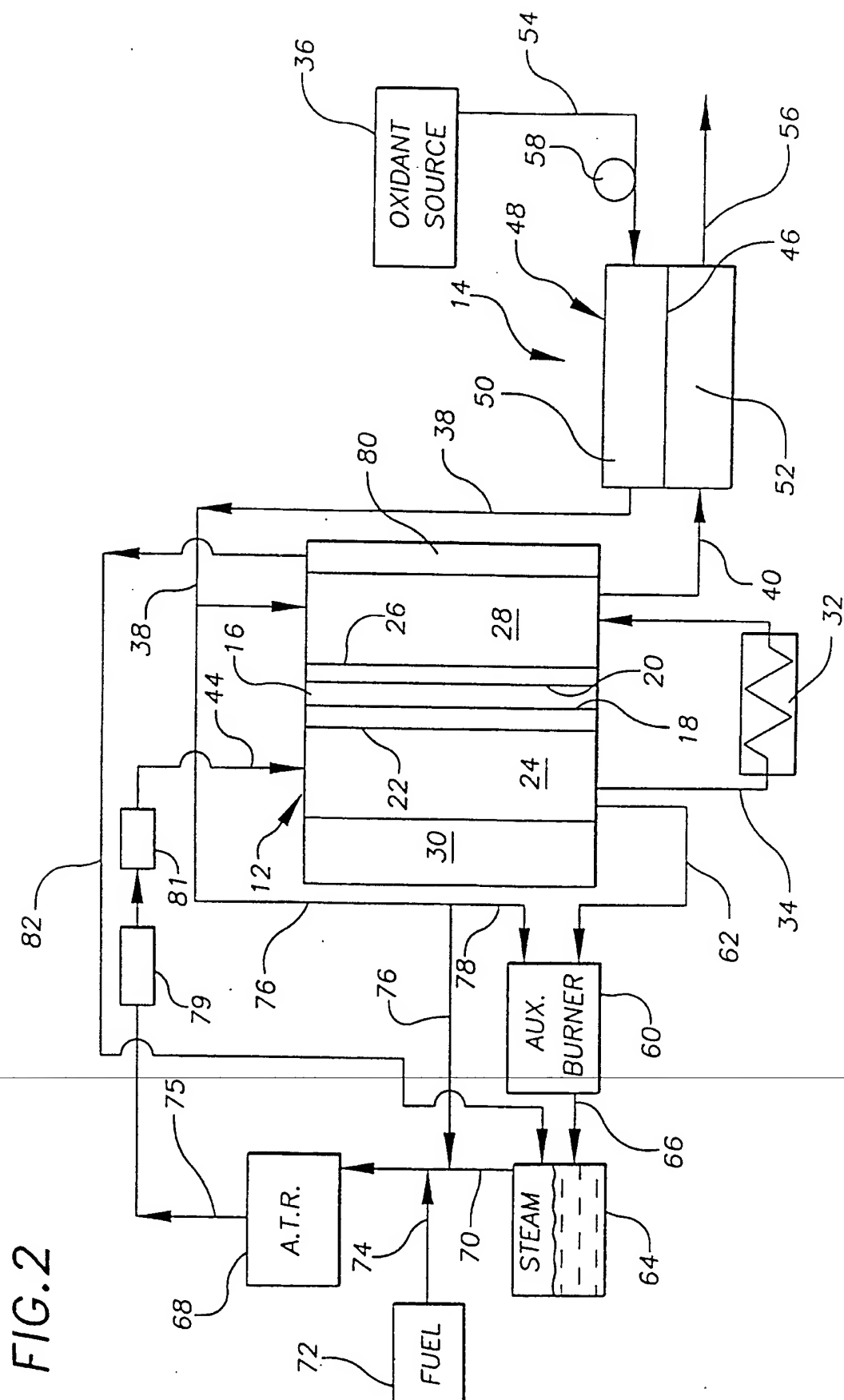
19. The method of operating the fuel cell power plant of Claim 18, further comprising the step of passing a portion the oxidant inlet stream through the secondary oxidant passage into a steam line providing steam and hydrocarbon  
5 fuel to a reformer of the plant and passing a portion of the oxidant inlet stream through a tertiary oxidant passage to an auxiliary burner providing heat to a steam generator of the plant.

20. The method of operating the fuel cell power plant of Claim 17, further comprising the step of directing the oxidant inlet stream and cathode exhaust stream in mass transfer relationship by passing the oxidant inlet stream  
5 and cathode exhaust stream in contact with a liquid water portion of an ionomeric membrane.

21. The method of operating the fuel cell power plant of Claim 17, further comprising the step of directing the oxidant inlet stream and cathode exhaust stream in mass transfer relationship by passing the oxidant inlet stream  
5 and cathode exhaust stream in contact with a liquid water portion of an ionomeric exchange tube.

FIG. 1





## INTERNATIONAL SEARCH REPORT

International application No.

PCT/US99/12255

<b>A. CLASSIFICATION OF SUBJECT MATTER</b> IPC(6) : HO1M 8/04, 8/06, 8/10 US CL : 429/13, 17, 20, 26, 30 According to International Patent Classification (IPC) or to both national classification and IPC		
<b>B. FIELDS SEARCHED</b> Minimum documentation searched (classification system followed by classification symbols) U.S. : 429/13, 17, 20, 26, 30 Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) APS fuel cell, heat transfer, mass transfer, sorb, desorb		
<b>C. DOCUMENTS CONSIDERED TO BE RELEVANT</b>		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5,503,944 A (MEYER et al) 02 April 1996, abstract, figure 1.	1-8, 17, 20, 21
--		-----
A		9-16, 18, 19
Y	US 5,542,968 A (BELDING et al) 06 August 1996, abstract, figure 1.	7
Y	US 5,759,712 A (HOCKADAY) 02 June 1998, column 12, lines 2-19.	1-8, 17, 20, 21
<input type="checkbox"/> Further documents are listed in the continuation of Box C. <input type="checkbox"/> See patent family annex.		
* Special categories of cited documents: *A* document defining the general state of the art which is not considered to be of particular relevance *E* earlier document published on or after the international filing date *L* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) *O* document referring to an oral disclosure, use, exhibition or other means *P* document published prior to the international filing date but later than the priority date claimed *T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention *X* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone *Y* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art *A* document member of the same patent family		
Date of the actual completion of the international search 14 DECEMBER 1999		Date of mailing of the international search report 23 DEC 1999
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230		Authorized officer WILLIAM LEADER <i>William Leader</i> Telephone No. (703) 308-0661